EFFECTS OF GRAIN LENTIL-WHEAT AND MONOCULTURE WHEAT ON CROP PRODUCTION AND N FERTILITY IN A BROWN LOAM

C.A. Campbell, V.O. Biederbeck, R.P. Zentner,
F. Selles and A.J. Leyshon
Agriculture Canada Research Station
Swift Current, Saskatchewan

ABSTRACT

Low commodity prices and a desire by producers on the Canadian Prairies to reduce fertilizer N inputs has resulted in a marked increase in grain lentil production in recent years. Because a large proportion of the pulse crop N is exported in the grain, it is generally believed that lentil, even though it fixes N_2, contributes little extra N to the soil system. Results of a 12-year study at Swift Current on an Orthic Brown Chernozem silt loam, were used to assess the N economy of four wheat rotations, of various lengths and levels of N fertilization, with a wheat-lentil (W-Len) rotation. Except for a continuous wheat (Cont W) system that received mainly P fertilizer, all other systems received N and P based on soil tests. Neither grain nor straw yields of the associated wheat crop were influenced by the presence of lentil in the rotation; but, N concentrations in both grain and straw of the wheat in W-Len were increased compared to the monoculture wheat. Nitrate N in the root zone (0-90 cm) in spring and at harvest was greatest under F-W, followed by W-Len, then F-W-W and Cont W receiving N and P, and lowest in Cont W receiving mainly P. In recent years, there was a marked increase in the amount of soil NO_3-N found in the root zone under the W-Len rotation. Similarly the estimated apparent net N mineralization during the growing season increased and the fertilizer N requirement for this system decreased, indicating a cumulative enhancement of the N supplying power of the soil. Therefore, soil testing laboratories should make a downward adjustment in their fertilizer N recommendations for producers that use a 2-yr W-Len rotation. Finally, there was less NO_3-N leached below the root zone of W-Len than Cont W (N+P) which augurs well for the use of this rotation for sustainability.

INTRODUCTION

The production of grain lentil (Lens culinaris medikus) and other pulse crops have increased markedly in western Canada in recent years. This has been partly the result of low commodity prices and partly the desire of producers to reduce fertilizer N inputs. In Saskatchewan, grain lentil is usually grown in rotation with cereals so that it may benefit the latter crop either through N enrichment of the soil by N_2-fixation, by leaving behind more residual moisture, or by unidentified secondary legume benefits (Baldock et al. 1981) or "rotational" effects (Russelle et al. 1987; Wright 1990).

Many studies with grain lentil have shown that this crop often exports more N from the system as grain than it fixes from the air (Bremer and Van Kessel 1989, 1992). Further, Bremer and Van Kessel (1992) found that the proportion of N recovered from the straw of grain lentil and wheat by a succeeding spring wheat crop was only 6% of that applied, while the proportion of N recovered was 19% with lentil green manure and 34% when $(NH_4)_2SO_4$-N fertilizer was used. Conversely, they found that most of the straw N was immobilized in soil, but 24% of the N in legume green manure and 30% of the fertilizer N were lost from the system.

In Saskatchewan, Bremer and Van Kessel (1989) have shown that grain lentil and spring wheat deplete soil moisture and soil mineral N to a similar extent. It is not surprising therefore, that the Saskatchewan Soil Testing Laboratory currently makes the same N recommendations for wheat whether it is grown after wheat or after grain lentil.

While researchers usually conduct fertility experiments on a new site each year so as to minimize residual effects of treatments from the previous year, producers generally grow their crops on the same land area each year. Because the uptake of N derived from the decomposition of grain legume residues is low, and since most of the residue N is immobilized, we can hypothesize that, on land where lentil is grown regularly for several years, a new equilibrium for soil available N may eventually be established leading to an enhancement of the soil's N supplying power. Conversely, if grain legumes are exporting more N via grain than is fixed by the crop, then the active pool of soil organic N may be gradually depleted (unless fertilizer is added to make up the shortfall) and this would result in the N supplying power of the soil being diminished over time.

Few long-term studies appropriate for testing these hypotheses exist in western Canada. In the long-term crop rotation study at the Agriculture Canada Research Station at Swift Current, Saskatchewan, (Zentner and Campbell 1988), a spring wheat-grain lentil rotation has been carried out for 12 years.

The objectives of this study were to determine the influence of grain lentil grown in rotation with hard red spring wheat on: (i) N supplying power of the soil; (ii) the N economy of the wheat-lentil system; (iii) the relative amount of soil moisture remaining at harvest after each crop, and (iv), to compare these results with those for several commonly used monoculture wheat rotations.

MATERIALS AND METHODS

Experimental Design

Details of the design and method of this experiment have been discussed previously (Campbell et al. 1983; Biederbeck et al. 1984; Zentner and Campbell 1988). Therefore, only a brief review is presented here together with some additional information pertaining to the wheat-lentil rotation which has not previously been discussed. The selected rotations are shown in Table 1.

The Swift Current crop rotation experiment was initiated in 1967 on a Swinton silt loam soil, an Orthic Brown Chernozem. When initiated, the soil had an organic nitrogen content of about 0.18% (0-15 cm depth) and a surface pH of 6.5 in water paste. Twelve crop rotations were established on 81, 0.04 ha plots in a randomized complete block design with three replicates. All phases of each rotation were present every year and each rotation was cycled on its assigned plots. During the first 12 yr, the criteria necessary for summerfallowing in two flexible continuous wheat rotations (9 and 10) were met on several occasions, but the action was not implemented; consequently, they were similar to rotation 8 (Table 1). In 1979, rotations 9 and 10 were changed to a spring wheat-grain lentil rotation.

Table 1. Crop rotations assessed

Rotation number	Rotation sequence	Fertilizer application	Plots
2	Fallow-wheat-wheat (F-W-W)	N and P	9
8	Continuous wheat (Cont W)	N and P	3
9†	Continuous wheat (Cont W)	(In first 12-yr; fallowed, if less than 60 cm of moist soil at planting time) N and P	3
10†	Continuous wheat (Cont W)	(In first 12-yr; fallowed if grassy weeds become a problem) N and P	3
11	Fallow-wheat (F-W)	N and P	6
12	Continuous wheat (Cont W)	P, but no N	3

†Rotations initiated in 1967 changed to wheat-lentil (W-Len) in 1979 because criteria were not assessed as intended and these rotations were, therefore, similar to rotation 8.

The field management (i.e., seedbed preparation, herbicide application, seeding, harvesting, and tillage of fallow areas) operations for spring wheat during the 1979-90 period were generally similar to those discussed previously (Campbell et al. 1983; Zentner and Campbell 1988). During the period 1979-1986, areas planted to lentil received one shallow tillage operation with a cultivator and mounted harrow to prepare a firm seedbed; after 1986 a light disking, followed by a cultivation and a harrow-packing operation were used to prepare the seedbed and to incorporate trifluralin (1.1 kg a.i. ha^{-1}), a pre-emergent herbicide into soil. The lentil seed (cv 'Laird') was inoculated with an appropriate Rhizobium and planted at a rate of 75 kg ha^{-1} at a depth of 5 cm in early to mid May of each year using a commercial hoe-press drill. Weed control in lentil was accomplished using metribuzin during the 1979 to 1986 period; in 1982 it destroyed the lentil crop, and in several other years some short-term crop injury was observed with this herbicide. As for wheat, lentil plots received a late fall application of 2,4-D ester for control of winter annual weeds.

Fertilizer N, as ammonium nitrate (34-0-0), was applied in accordance with rotation specifications at rates based on soil tests of the individual plots. All rotations that were designated to receive P received ammonium phosphate (11-48-0) at an annual rate of 10 kg ha^{-1} of P placed with the seed.

Soil and Plant Sampling and Analyses

In spring (usually early May) and at harvest (usually late August), soil samples were taken from the 0- to 15-, 15- to 30-, 30- to 60-, 60- to 90- and 90- to 120-cm depths of each plot and analyzed for moisture gravimetrically and NO_3-N. Gravimetric moisture content was converted to volumetric units using bulk densities of 1.22, 1.28, 1.36, 1.39 and 1.55 Mg m^{-3} for the five depths, respectively (Campbell et al. 1983). Wheat grain yields were determined by harvesting with a farm sized combine. Grain and straw were dried at 60°C, weighed, ground to <1 mm and their N concentrations determined. When the first pods on the lentil plants turned brown, three subsamples, each 2.32 m^2, were randomly taken of the total above ground plant material from each plot. After drying, the samples were separated into grain and straw and analyzed for their N concentration as for wheat. During 1979 to 1986, lentil was swathed and later threshed with a conventional combine for yield determination. From 1987 to 1990, the lentil plots were desiccated with diquat and harvested using a small plot combine.

An estimate of the apparent net N mineralized (N_{min}) during each growing season was calculated as follows:

$$\text{Plant N} + SN_{harvest} + \text{N lost} = SN_{spring} + FN + N_{min} + N_{fixed} \quad . \qquad (1)$$

Where SN = soil NO_3-N in 0- to 90-cm depth. [In this soil NO_3-N in the 90-to 120-cm depth is usually quite erratic (Campbell et al. 1983)]. Because we had no reasonable estimates of N lost through leaching and denitrification, and because all systems were cropped, we assumed these to be negligible. We also had no reasonable method of estimating N fixation by lentil and, to simplify calculations, we assumed this to be zero. Roots were not measured but estimates of root N was taken as 0.6 x straw N (Campbell and Paul 1978).

On July 31, 1990, a Giddings soil corer was used to take samples by 30-cm increments to 300 cm depth from the Cont(W) (N+P) and (W)-Len (N+P) rotations. Two holes were taken per plot from each of the 3 replicates and these analyzed separately. Subsamples were taken from each segment for bulk density determination and the remaining soil used to determine moisture (gravimetrically) and NO_3-N.

In September 1990, soil samples were taken from the 0- to 15-cm depth of the fallow phases of F-W and F-W-W rotations and from the wheat phases of Cont W and W-Len rotations. The soil was screened through 2 mm sieve, air-dried, and a month later it was used to determine potentially mineralizable N (N_o), the rate constant (k), and the initial potential rate of N mineralization ($N_o k$) (Campbell et al. 1991a). Soil-sand mixtures were incubated at 35°C with intermittent leaching using an N-minus nutrient solution followed by determination of mineral N formed over a 16-wk period.

Statistical Analyses

Several factors were analyzed over the 12 yr period 1979-1990. A split-plot design was used with year as main plot and rotation phase as sub-plot. Factors assessed in this way were: (i) soil moisture (0- to 120-cm depth), and (ii) soil NO_3-N (0-to 90-cm depth), both at spring and harvest; (iii) weight, N concentration, and N content of grain and straw, and (iv) plant (including estimated roots) N content. LSD ($P<0.05$) for main effects and the year x rotation phase interactions were calculated